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A Five-Year Study of Mercury in Fish from a Newly Formed Reservoir (Gleniffer Lake, Alberta)

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A FIVE-YEAR STUDY OF MERCURY IN FISH FROM A NEWLY FORMED RESERVOIR (GLENIFFER LAKE, ALBERTA)

by

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SUMMARY

The purpose of this study was to assess changes in the concentration of mercury in the muscle tissues of fish collected from a newly formed reservoir (Gleniffer Lake, Alberta). The study was conducted over a five-year (1983-1987) period. It has been concluded that:

i. Mercury residues in all major species (northern pike, Esox lucius; burbot, Lota lota; rainbow trout, Oncorhynchus mykiss; white sucker, Catostomus commersoni; longnose sucker, Catostomus catostomus; mountain whitefish, Prosopium williamsoni) were low, generally falling below 500 μg kg^{-1} (0.5 ppm).

ii. Using fish of standard fork length, mercury residues in fish varied inconsistently from year to year, showing no significant increase over time.

iii. No limits need to be placed on consumption of fish from Gleniffer Lake.

PROJECT TEAM

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1. INTRODUCTION

1.1 Background

The adulteration of fish tissues with mercury first became a pervasive environmental issue approximately 30 years ago with the poisoning of people around Minamata Bay, Japan (Mitra, 1986). The symptoms of the poisonings were striking, affecting the central nervous system, and producing birth defects and death in severe cases. Although the magnitude of Minamata disease (as it is now termed) stimulated agencies around the world to regulate mercury discharges, several other less severe cases of poisoning were reported among fishermen and others in several countries during the 1960s and early 1970s (Mitra, 1986). This further stimulated regulatory agencies to control and monitor mercury contamination in the environment.

In recent years, most western nations have developed regulations which either restrict or severely limit the quantity of mercury discharged from point sources. Although this has greatly reduced the level of environmental contamination of mercury in most areas, nonpoint sources of mercury continue to be difficult to regulate. Geologic formations may be naturally high in mercury, particularly in areas of volcanic activity (Jonasson and Boyle, 1972). The western part of Alberta lies in one such belt.

Newly formed reservoirs are a nonpoint source of mercury. Immediately after flooding, the rate of methylation in freshly

inundated soils increases which, in turn, increases uptake of organic mercury in fish and other aquatic species (Cox et al., 1979). This increase in mercury has been noted in many impoundments in Canada and several other places in the world (Abernathy and Cumbie, 1977; Benson et al., 1976; Bodaly et al., 1984; Bodaly and Hecky, 1979; Bruce and Spencer, 1979; Cox et al., 1979; Kent and Johnson, 1979; Knight and Herring, 1972; Meister et al., 1979; Potter et al., 1975; Smith et al., 1974).

Residues of over 3 mg kg^{-1} (ppm) in fish tissues have been reported in some of the above-noted studies. This can be compared to the consumption guideline in Canada of 0.5 mg kg^{-1} (Ministry of Environment, 1983). Eventually reducing conditions develop in older reservoirs, causing a decrease in the activity of methylating bacteria and the amount of organic mercury available to fish and other aquatic species (Cox et al., 1979).

1.2 Gleniffer Lake

Gleniffer Lake was created with the construction of Dickson Dam on the Red Deer River approximately 40 km southwest of the City of Red Deer (Figure 1). Clearing of the site and construction of access roads began in February 1980. By the spring of 1983, the dam was completed and the reservoir began filling. The reservoir has an area of 1734 ha at full storage and measures approximately 11 km in length and 2 km in width. The design discharge of the facility is 38 m^3 sec^{-1} and the annual flush rate is approximately 5.5. The reservoir

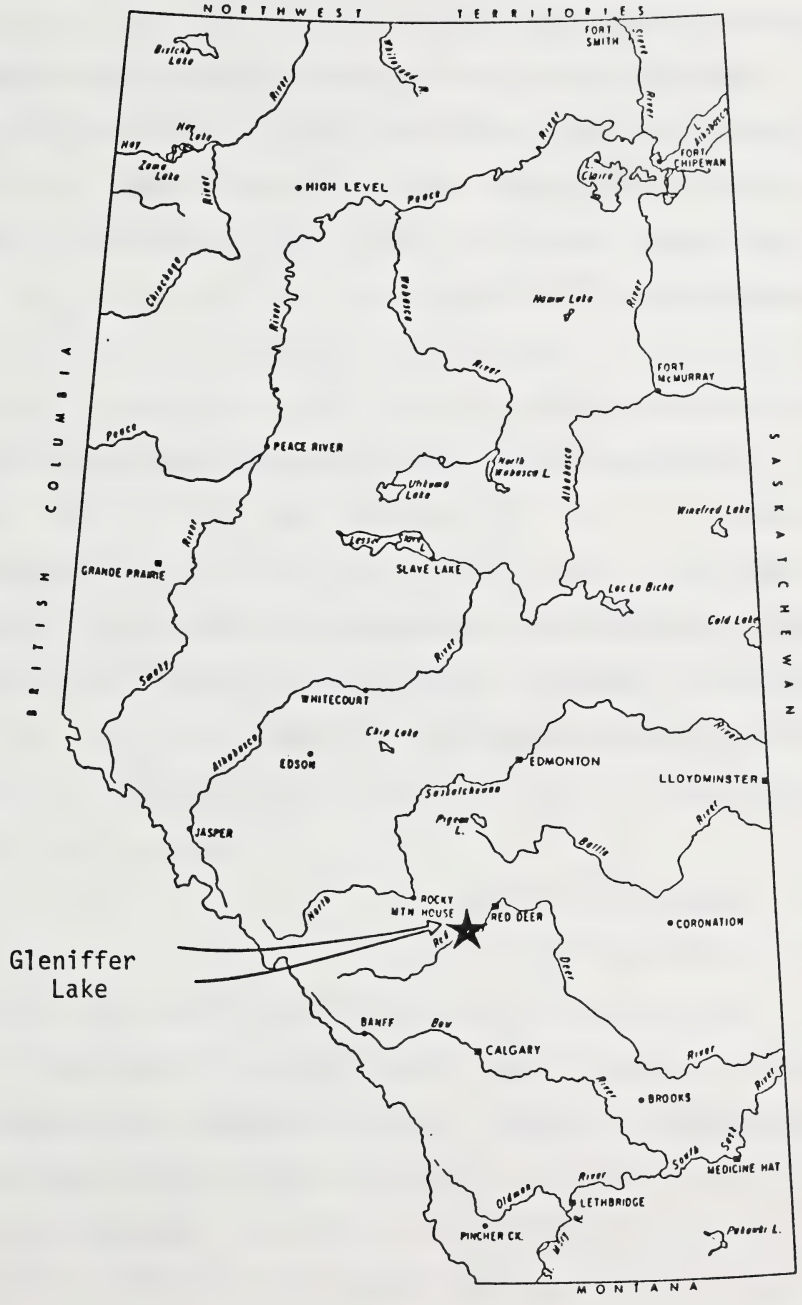

Figure 1. Location of Gleniffer Lake.

has a maximum depth of approximately 32 m at full service level with a usable storage volume of 203 x 10^6 m^3.

Juvenile rainbow trout (Oncorhynchus mykiss) were planted annually in Gleniffer Lake from 1983 to 1987 (Fish Planting List, 1983-1987). Cutthroat trout (Salmo clarki) were also planted in 1983 and brown trout (Salmo trutta) in 1984. Total plantings for all species amounted to 1,096,000 fish.

1.3 Purpose of Study

The purpose of this study was to determine changes in the mercury content of fish in Gleniffer Lake over a five year period (1983-1987). This information would then be useful in establishing a policy regarding the consumption and other uses of fish from the reservoir. Population studies on fish in Gleniffer Lake were done at the Alberta Environmental Centre (1989).

2. MATERIALS AND METHODS

2.1 Collection of Fish

The species collected in sufficient numbers to warrant analysis were: northern pike (Esox lucius), white sucker (Catostomus commersoni), longnose sucker (Catostomus catostomus), mountain whitefish (Prosopium williamsoni), burbot (Lota lota), and rainbow trout. Only 3 brown trout, 1 brook trout (Salvelinus fontinalis) and 1 dolly varden (Salvelinus malma) and no cutthroat trout were caught

during the entire study. Fish were collected using multi-panel gill nets, measuring 50 m in length, 1.8 m in depth and made of green or colourless monofilament nylon. Two nets were usually tied together, yielding a total net length of 100 m. Mesh sizes were 1.9, 2.5, 3.8, 5.1, 6.4, 7.6, 8.9, 10.2, 11.4 and 12.7 cm. There were two sampling sites in each of the three basins (Figure 2). One site was situated in shallow (<10 m) water and the other in deep (>10 m) water. Each net was usually set in the morning and left for 24 h. All collections were made during September or October of each year. Angling was also used to supplement the small catch of rainbow trout in the gill nets.

2.2 Tissue Preparation

A 100-150 g sample of dorsal muscle fillet was dissected from an area anterior to the adipose fin of each fish within 6 h of collection. The sample was wrapped in distilled-water-rinsed aluminum foil and placed in individual plastic bags. All of the tissues were frozen to -20°C until analysis.

2.3 Mercury Analysis

2.3.1 Apparatus

a. LDC (Laboratory Data Control, U.S.A.) Mercury Monitor equipped with a mercury hollow cathode lamp emitting monochromatic light at 253.7 nm.

Figure 2. Gill net sampling sites. Deep set (>10 m); shallow set (<10 m).

b. Long path dual gas cell assembly (30 cm long and 0.75 cm diameter) made of rigid polyvinyl chloride with quartz lens windows at both ends.

c. Chart recorder.

d. Specially designed and constructed pyrex glass mercury reduction-bubbler assembly.

e. Pure nitrogen gas source (standard cylinder) with two-stage exit regulator for constant gas delivery at a low flow rate.

f. Constant temperature shaker bath with gable cover, platform and clips to hold 20 or more glass digestion tubes, with a total capacity of 24-35 litres of water.

g. Automatic pipetter dispensers.

h. Pipetters with disposable tips.

i. Stop watch.

j. Magnetic stirrer.

k. Homogenizer (Waring blender) or standard electrical blender with special mini-blending jars.

2.3.2 Sample Preparation

About 15 g of fish muscle tissue free of bone and fat was blended with 7.5 mL of 0.1N H_2SO_4 in a stainless steel blending cup until a smooth paste was obtained. Usually 30 sec of blending time was sufficient to produce an homogeneous paste.

The wet homogenate (1 g) was weighed accurately into four digestion tubes. One aliquot was weighed into a Petri

dish and left loosely capped in a forced-air oven for 24 h at 55°C to determine the wet/dry weight ratio. If a delay (>1 day) in analysis was anticipated, the aliquots were stored at -20°C in sealed polypropylene cups.

2.3.3 Sample Digestion

To two of the four aliquots in the digestion tubes, the digestion mixture added was: 1 mL of 20% NaCl solution, 1 mL of 1% cysteine solution and 10 mL of 16N H_2SO_4. The tubes were tightly stoppered in a shaker water bath at 55-60°C for 1 h. Thorough mixing was ensured by adjusting the shaking speed. If the samples were not completely mixed after 1 h, they were shaken for an additional 0.5 h. The tubes were then removed from the bath and cooled to room temperature. The sides and the stopper of the tubes were rinsed with minimum d.d.w. (distilled deionized water) and made up to a known volume. The digested solutions were analyzed within 24 h.

To the remaining two aliquots in the digestion tubes, 5 mL of the digestion acid mixture (1 mL of conc. HNO_3 + 4 mL of conc. H_2SO_4) was added. The tubes were stoppered tightly, fitted into a rack and shaken in a water bath at 55-60°C for 2 h or until a clear solution was obtained. The tubes were removed from the bath and cooled to room temperature. 15 mL of 6% $KMnO_4$ solution was added slowly and allowed to stand for 30 min. If the purple colour

disappeared at this stage, more $KMnO_4$ was added until the colour persisted. Then 30% H_2O_2 solution was added with caution while stirring until the precipitate just dissolved. The solutions were made to a known volume and mixed well. The solutions were analyzed within 24 h.

2.3.4 Calibration and Analysis

Stock (100 mg L^{-1}), intermediate (220 µg L^{-1}) and working standard solutions (0.1-1.0 µg L^{-1}) of inorganic mercury as mercuric chloride ($HgCl_2$) and total mercury as $HgCl_2$ plus CH_3HgCl were prepared. Further data on standards and calibration curves are given in Alberta Environmental Centre (1982).

2.3.5 Total Mercury Analysis

Exactly 15 mL of total mercury standard solution was pipetted into a digestor-analysis tube. 5 mL of the digestion acid mixture (conc. HNO_3 + conc. H_2SO_4, 1:4 ratio) was added to the standard solution. The tubes were stoppered tightly, fitted into a rack and shaken in a water bath at 55-60°C for 2 h or until a clear solution was obtained. The tubes were removed from the bath and cooled to room temperature. 15 mL of 6% w/v $KMnO_4$ solution was added and allowed to stand for 30 min. If the purple colour disappeared, more $KMnO_4$ solution was added until the colour persisted. A solution of 30% H_2O_2 was added cautiously with stirring until the precipitate just dissolved. The

solution was made up to a known volume and mixed thoroughly. The total mercury was analyzed as described here.

The tube was placed in position with the bubbler and flushed with N_2 gas to remove any interfering vapors. 1 mL of $SnCl_2/NH_2OH$ solution and 2 mL of 45% NaOH solution were added in quick succession. After 30 sec (using a stop watch), the mercury vapor produced was flushed by pure N_2 gas into the Mercury Monitor and the peak absorbance was recorded. When the absorbances began to decline, the 4-way valve was turned into the bypass position and the bubbler tube was rinsed off.

The next standard solution was analyzed following the previous steps. The blanks (all reagents except mercury) were analyzed as stated above to detect any blank interference. Digested blanks and standards were also analyzed to detect any artifact introduced during the digestion stage. All samples digested for inorganic mercury analysis (sample digestion [1]) were analyzed following these above steps.

2.3.6 Quality Control and Assurance

2.3.6.1 Quality Control

In addition to vigorous implementation of good laboratory practices regarding reagents glassware, plasticware, maintenance of equipment, etc., routine quality control checks were made on the water, reagent blanks and the

analytical detection system including the lamp intensity. For every sample, total mercury was analyzed in duplicate. Thus, 10 fish generated 20 samples for Hg analysis and each batch of 20 samples included two internal check standards. In addition, one mid-calibration standard for every 10 samples was analyzed as a quality control check during analysis.

2.3.6.2 Quality Assurance

In addition to routine intra-laboratory quality control checks, the laboratory participates year-round in the National Interlaboratory Mercury in Fish Quality Assurance Program, conducted four times a year by the Federal Department of Fisheries and Oceans, Winnipeg, Canada. The participation began in 1982 when the mercury analysis commenced in Aquatic Biology Branch and its performance was satisfactory.

2.4 Statistical Analysis and Interpretation of Data

A total of 1 to 20 fish was analyzed from each species per year. The mean concentration of mercury found in each fish was analyzed by statistical regression against fish fork length. Fork length was selected as the independent variable because it is easier to determine by consumers of fish than either age or weight.

The model used in these studies was $X = a + bL + c$, where X is the concentration of mercury in each fish, a is the intercept, b is the

regression coefficient or slope, L is the fork length of the fish, and c is the random error term associated with each measurement.

The empirical relationship between fish consumption and concentration of mercury in a fish of given length was derived by using the 95% confidence limit of the regression line. The upper confidence limit was chosen to derive guidelines for consumption because it provides a relatively greater margin of safety than use of mean data. Hence, if the 95% confidence limit in a fish of specified length exceeded the guideline established for a certain contaminant, then consumption of the size class was either limited or restricted. The consumption guideline for this study is 500 $\mu g\ kg^{-1}$ (0.5 $mg\ kg^{-1}$).

3. RESULTS

3.1 Fish Size and Mercury Residues

Based on the linear regression models in Figures 3-7, mercury residues increased with the size of most fish in most years. Rainbow trout was the main exception, showing a decline in mercury with fish length. This inverse relationship is probably related to the planting in the reservoir of large, hatchery-reared trout, containing relatively low mercury residues. The regression parameters relating length of fish to the concentration of mercury in muscle tissue are listed in Table 1.

3.2 Time-Related Changes in Mercury Residues

Changes in the concentration of mercury in fish during the period 1983-1987 were determined in fish of standard length using the linear regression parameters in Table 1. The standardized lengths used were: northern pike, 50 cm; burbot, 50 cm; white sucker, 40 cm; longnose sucker, 40 cm; mountain whitefish, 25 cm; rainbow trout, 50 cm.

Based on these calculations, mercury residues in northern pike averaged 310 $\mu g\ kg^{-1}$ in 1983, declining to 188 $\mu g\ kg^{-1}$ in 1987 (Table 2). Residues in burbot also declined whereas the pattern of change in white sucker and longnose sucker was less consistent. Residues in mountain whitefish increased substantially in 1984 and 1985, prior to the disappearance of the species in our catches.

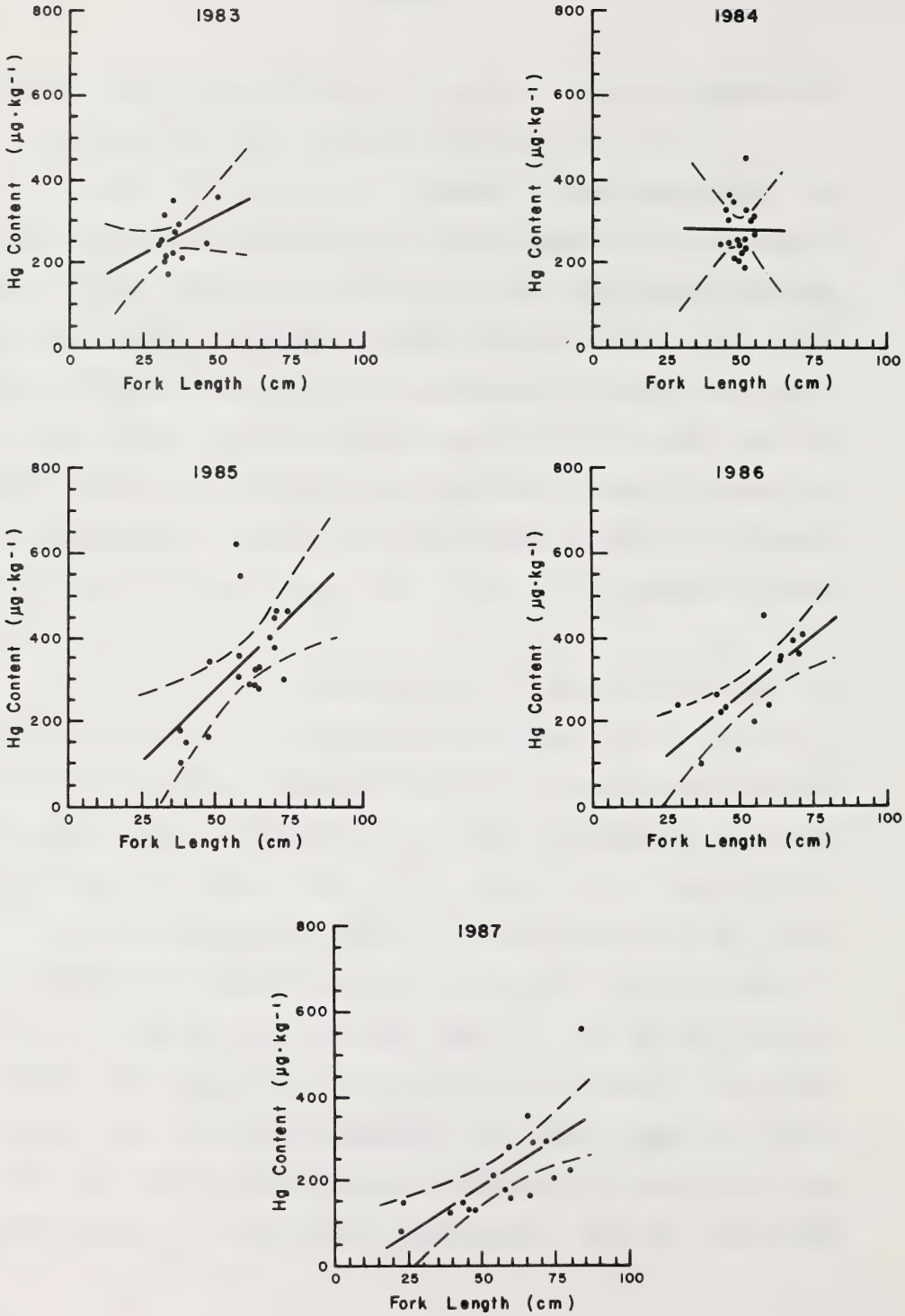

Figure 3. Linear regression analysis relating the concentration of mercury (± 95% confidence limits) in the muscle tissue of northern pike of different fork length collected from Gleniffer Lake, 1983–1987.

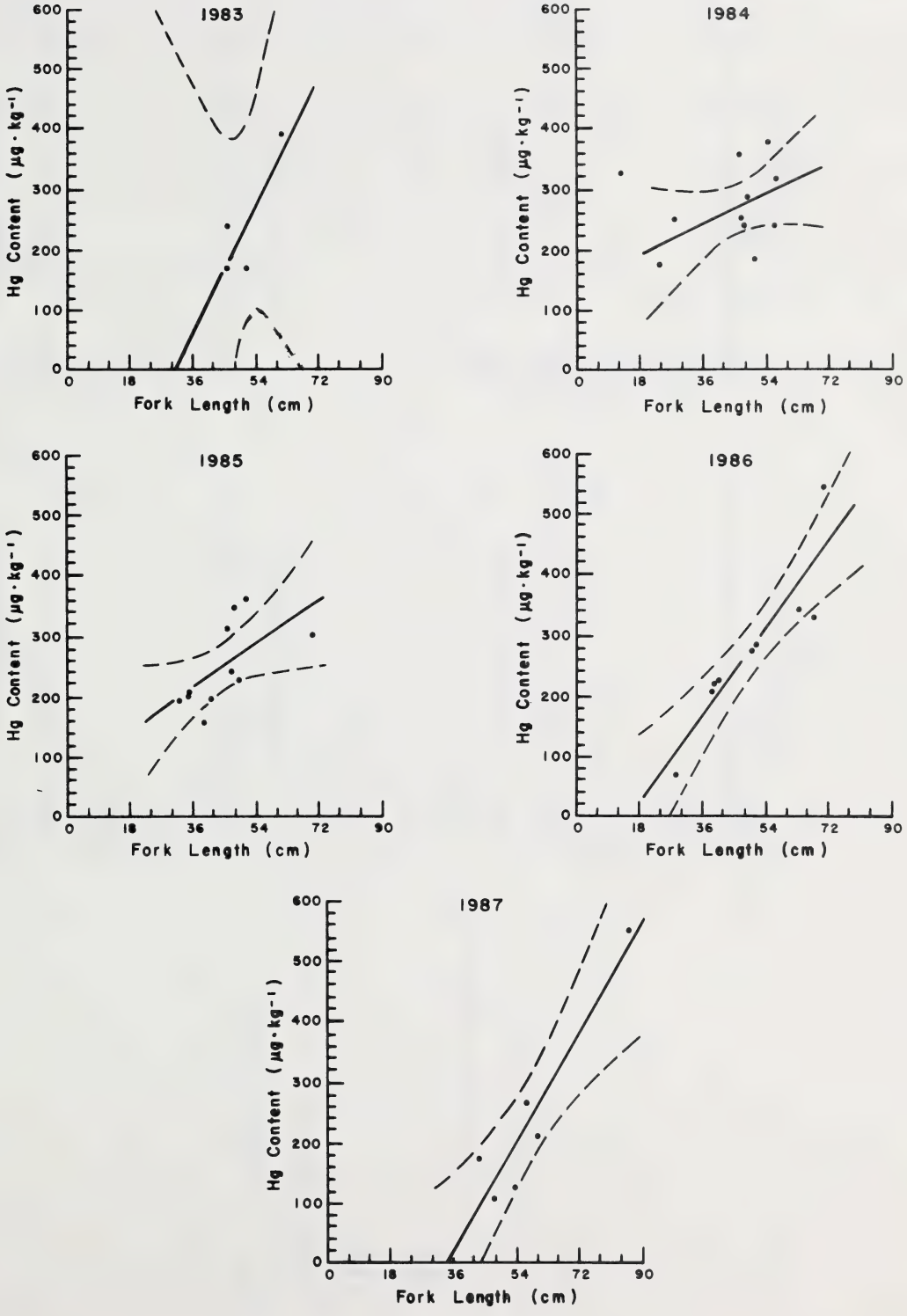

Figure 4. Linear regression analysis relating the concentration of mercury (± 95% confidence limits) in the muscle tissue of burbot of different fork length collected from Gleniffer Lake, 1983–1987.

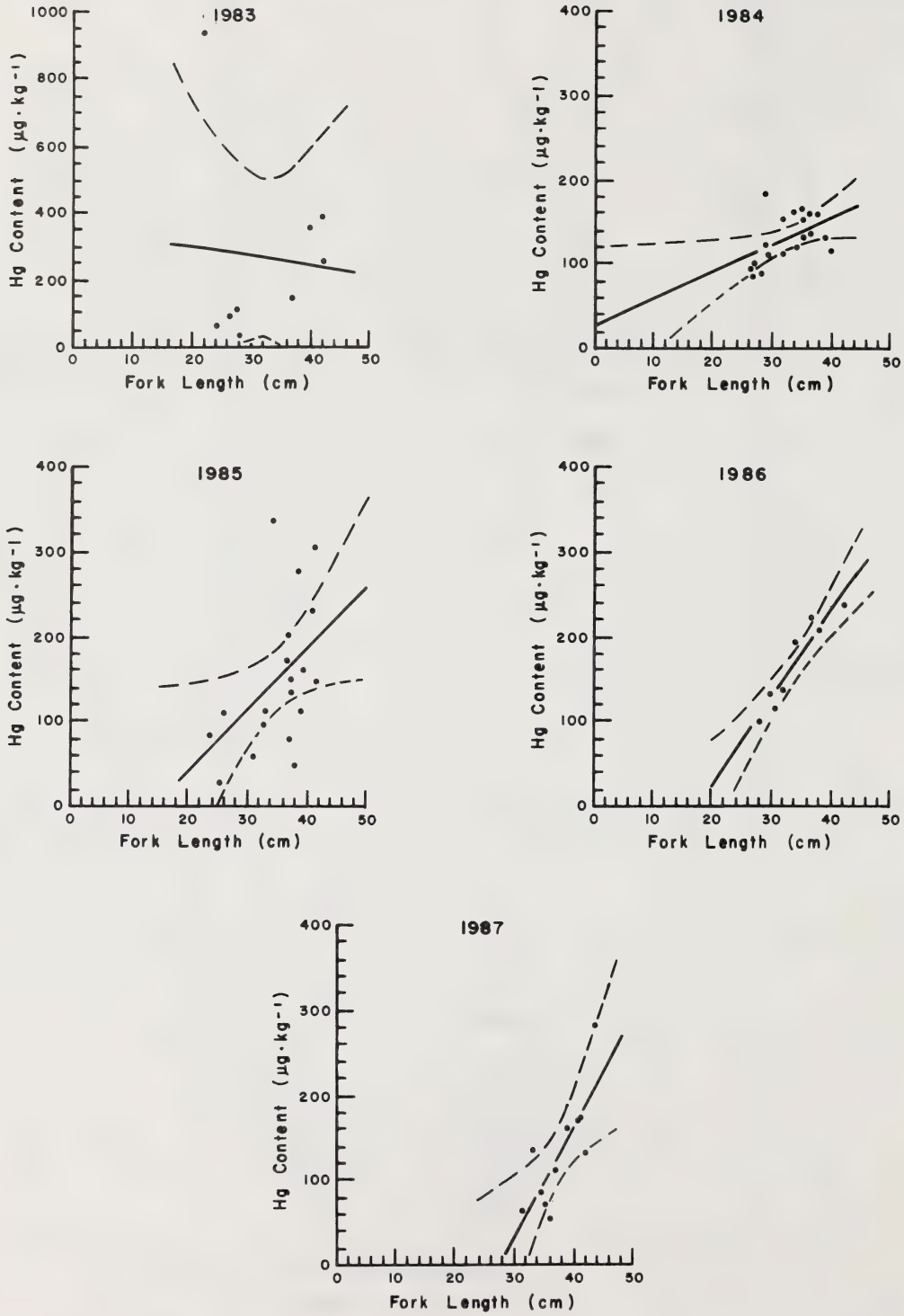

Figure 5. Linear regression analysis relating the concentration of mercury (± 95% confidence limits) in the muscle tissue of white sucker of different fork length collected from Gleniffer Lake, 1983–1987.

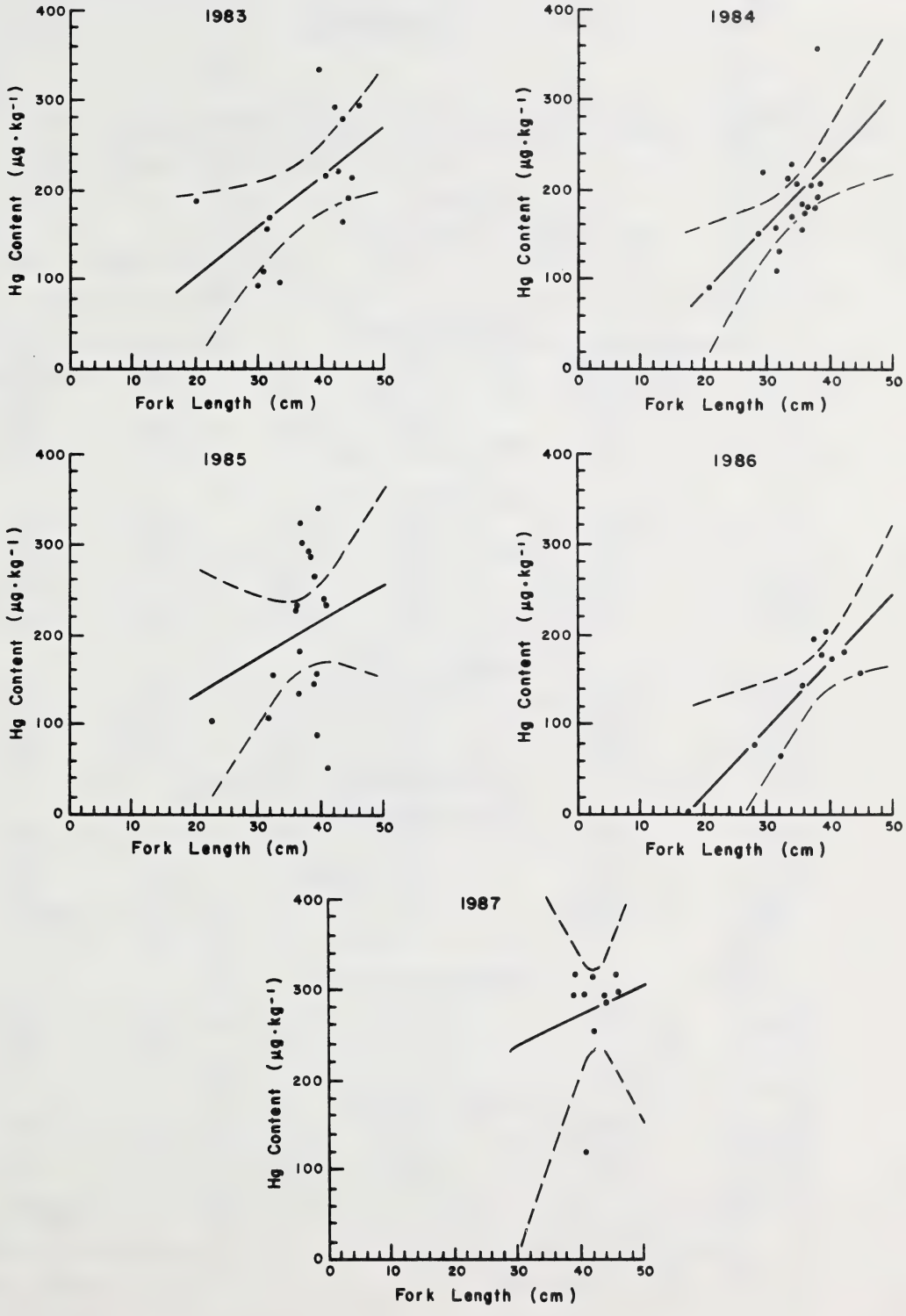

Figure 6. Linear regression analysis relating the concentration of mercury (± 95% confidence limits) in the muscle tissue of longnose sucker of different fork length collected from Gleniffer Lake, 1983–1987.

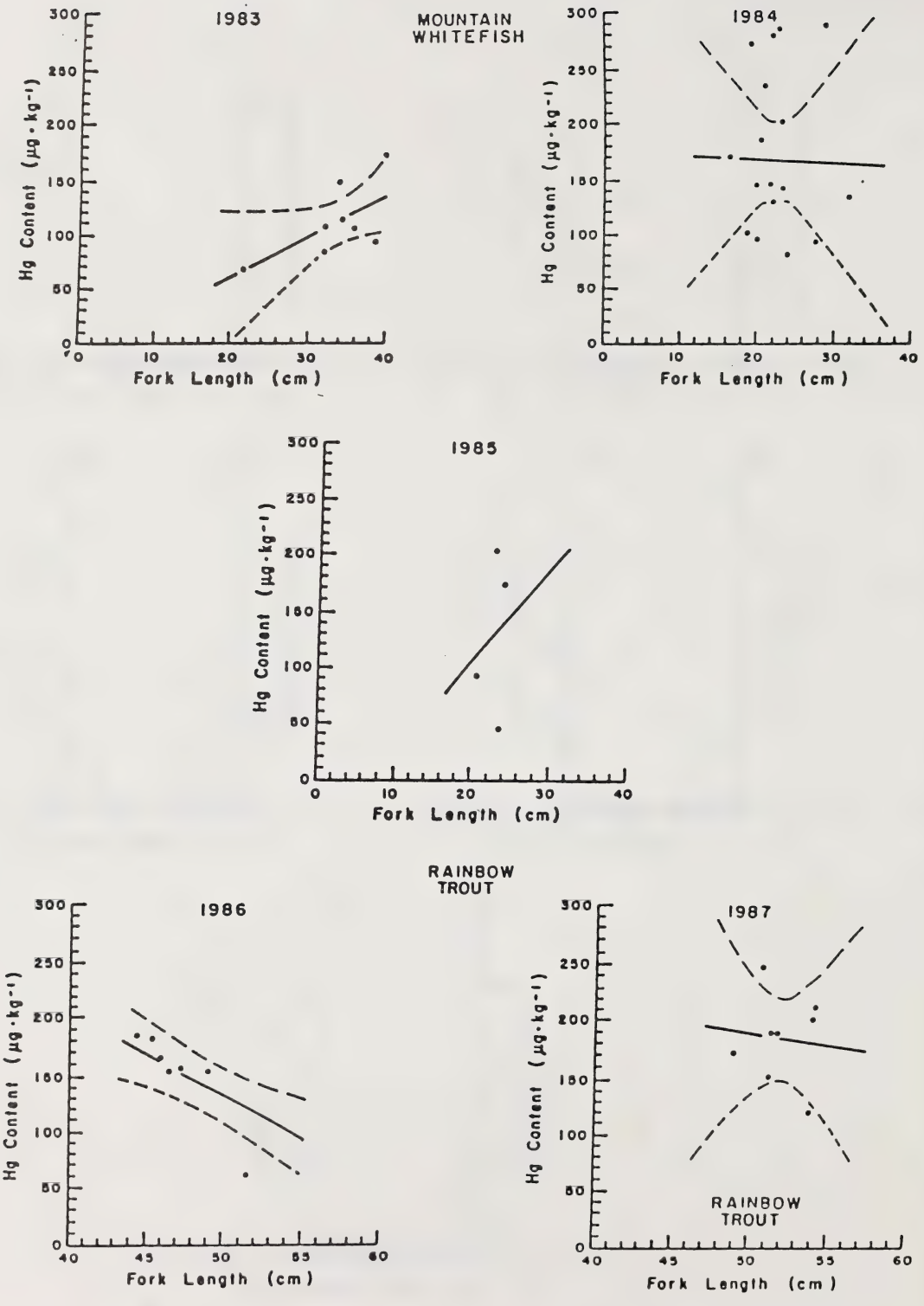

Figure 7. Linear regression analysis relating the concentration of mercury (± 95% confidence limits) in the muscle tissue of mountain whitefish and rainbow trout of different fork length collected from Gleniffer Lake, 1983–1987.

Table 1. Linear regression parameters relating the concentration of mercury in the muscle tissue and fork length of fish collected from Gleniffer Lake.

Year	Intercept	Slope	Standard Error	Correlation Coefficient	R^2
			NORTHERN PIKE		
1983	128.4	3.6	50.2	0.40	0.16
1984	289.8	-0.2	65.3	-0.01	0.01
1985	-71.1	6.8	107.5	0.60	0.36
1986	-23.2	5.7	73.0	0.73	0.54
1987	-36.9	4.5	82.9	0.70	0.49
			BURBOT		
1983	-366.1	11.8	73.6	0.82	0.67
1984	140.1	2.7	58.6	0.47	0.23
1985	66.3	4.0	57.0	0.63	0.40
1986	-127.1	8.0	56.7	0.91	0.83
1987	-346.1	10.1	62.8	0.94	0.88
			WHITE SUCKER		
1984	26.9	3.2	25.3	0.49	0.24
1985	-103.0	7.2	76.1	0.48	0.23
1986	-190.3	10.5	19.1	0.94	0.89
1987	-351.6	12.8	45.6	0.76	0.58
			LONGNOSE SUCKER		
1983	-9.4	5.5	62.9	0.57	0.32
1984	-65.3	7.4	46.3	0.57	0.33
1985	48.0	4.1	82.4	0.25	0.06
1986	-127.5	7.4	34.3	0.76	0.57
1987	133.9	3.3	60.0	0.15	0.02
			MOUNTAIN WHITEFISH		
1983	-12.6	3.8	26.9	0.62	0.38
1984	175.1	-0.4	74.7	-0.02	0.00
1985	-58.1	8.3	87.6	0.17	0.03
			RAINBOW TROUT		
1983	59.0	7.2	4.4	0.99	0.98
1985	727.7	-12.1	14.3	-0.83	0.70
1987	292.6	-2.0	40.7	-0.10	0.01

Mercury in rainbow trout increased in 1986 and 1987, the only years in which enough trout were caught to warrant analysis.

Table 2. Mean (± 95% confidence limits) content of total mercury ($\mu g\ kg^{-1}$) in fish of standard length based on linear regression calculations.

Year	Northern Pike	Burbot	White Sucker	Longnose Sucker	Mountain Whitefish	Rainbow Trout
1983	310±75	225±17	250±34	213±40	82±40	ND
1984	275±30	278±30	156±22	232±42	159±42	ND
1985	272±70	270±35	184±45	213±40	272*	ND
1986	263±40	277±40	231±30	169±35	ND	132±22
1987	188±50	160±80	160±45	268±50	ND	190±52
Standardized Length (cm)	50	50	40	40	25	50

*95% confidence limits not calculable; ND, no data.

3.3 Consumption Limits

The 95% confidence limit relating the concentration of mercury to the length of fish was below 500 $\mu g\ kg^{-1}$ in mountain whitefish, rainbow trout and longnose sucker (Figures 6 and 7). Therefore no consumption limit needs to be placed on these species. Similarly the 95% confidence limits for northern pike, white sucker and burbot were, with some exceptions, generally <500 $\mu g\ kg^{-1}$, regardless of fish size (Figures 3-5). Since these exceptions were restricted to large

fish and were always only marginally over the guideline, no consumption limits need to be placed on any species.

4. DISCUSSION

Mercury residues in fish from Gleniffer Lake were low compared to most other lakes and rivers in Alberta. For example, total mercury in northern pike from the Red Deer River averaged 310 μg kg^{-1} (maximum 480 μg kg^{-1}) compared to the 1987 average in Gleniffer Lake of 190 μg kg^{-1} (maximum 350 μg kg^{-1}) (Alberta Environmental Centre, 1984). Similarly, in the North Saskatchewan River, residues in pike also averaged 310 μg kg^{-1} with a maximum of over 1000 μg kg^{-1} (Alberta Environmental Centre, 1986). Although consumption of fish from both rivers is either limited or restricted due to mercury contamination, no guidelines need to be placed on the consumption of fish from Gleniffer Lake.

The reasons why mercury residues in fish from Gleniffer Lake are low are not known. Based on examples from other newly formed reservoirs, residues would be expected to increase rather than remain low. The uptake of mercury by fish is largely dependent upon the presence of organic mercury, which is produced in the environment by the activity of methylating bacteria. Since almost nothing is known about the factors controlling the activity of such bacteria under

natural conditions, we can only speculate as to why there was no increase in mercury in fish tissues.

Given the fact that mercury accumulation has been observed in relatively cool reservoirs in northern Manitoba (Bodaly and Hecky, 1979) and Labrador (Bruce and Spencer, 1979), the relatively cool conditions in Gleniffer Lake should have had little impact on bacterial activity. Similarly, since mercury accumulation in newly formed reservoirs has been observed in many different types of watershed, land use conditions do not appear to control the activity of methylating bacteria. Berman and Bartha (1986) did note that sulphide inhibits the formation of methylmercury in sediments. Such measurements could not be taken in this study due to the depth of the reservoir and restraints on technical assistance.

Because we do not know about the factors which control the methylating bacteria in Gleniffer Lake, it is important not to extrapolate the results of this study to other reservoirs under construction or planned for the Province of Alberta.

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